

WHERE ARE WE AND WHERE SHOULD WE GO?

Summary Reports of the Girona Conference Workshops

BUELL T. JANNUZI

*National Optical Astronomy Observatories
P.O. Box 26732, Tucson, AZ 85726, USA*

ALAN P. MARSCHER

*Department of Astronomy, Boston University
725 Commonwealth Ave., Boston, MA 02215, USA*

MARTIN POHL

*Max-Planck-Institut für Extraterrestrische Physik
Postfach 1603, 85740 Garching, Germany*

AND

ALEX G. SMITH

*University of Florida Department of Astronomy, 211 Space
Sciences Building, Gainesville, FL 32611, USA*

1. Introduction

After nearly four days of listening to our colleagues describe their latest results on jets, black holes, and blazars, the conference organizers gave the participants a chance to take stock of how much (or how little) has been learned about blazars and speculate about future directions of research. Four parallel workshops were organized and conference attendees were free to choose at which session they would like to present and debate their ideas for the duration of an afternoon, with opportunities for coffee and cookies to stimulate the discussion. The chosen topics were “Jet Models”, “Multi-Frequency Support for High-Energy Observations”, “Monitoring of Blazars”, and “Host Galaxies and Environments”. While the individual sessions focused on their assigned topic, the goals of all the sessions were to identify points of agreement in the field and to set a course for future research. Following several hours of lively discussions, each session chair presented to the entire conference a summary of their own group’s discussion. In this collective summary we have tried to reproduce the main opinions and ideas that were generated during the workshops. The individual workshop

summaries are presented in the following subsections and were prepared by the respective session chairs: “Jet Models”, Marscher; “Multi-Frequency Support”, Pohl; “Monitoring of Blazars”, Smith; and “Host Galaxies and Environments”, Jannuzi.

2. Jet Models

2.1. INTRODUCTION

What do you get when you lock up about twenty blazar theorists in a room for an hour and a half? The answer at the outset was not clear: 100% annihilation of theorists and their corresponding anti-theorists? Anarchy followed by one strong-armed astrophysicist taking over as dictator and forcing his/her ideas on everyone else? General agreement on the status of the field and the things to do next, with everyone leaving the room arm-in-arm, singing “Give Peace a Chance” in perfect five-part harmony? I was very pleasantly surprised — shocked, even, but perhaps that’s because I like models with shocks so much — that the result was much closer to the last of these choices than the former two. It seems that there is a widespread consensus on the next steps to take in jet modeling and simulation. In the following brief report, I summarize the current status of the field and the direction of future efforts that the participants in the workshop feel would be most fruitful toward understanding blazars, which we all know are the most interesting objects in the universe.

2.2. NATURE OF THE JETS

While most models are based on the assumption that the jet is a plasma flowing at a relativistic speed that is the same speed needed to explain the observed apparent superluminal motion, this is not necessarily true. In fact, there are some disturbingly rapid variations (e.g., the recent factor-of-20 TeV flare in Mkn 421 on a timescale of less than half an hour) that are pushing us toward ever higher Doppler factors. One suggestion is that the underlying phenomenon is an invisible particle beam with very high Lorentz factor (10^4 to 10^6) that interacts somewhat with the external medium to produce secondary, but visible features that move at the much slower (Lorentz factor ~ 3 –20) speeds seen in VLBI images. It would be natural for such beams to be composed of electrons and positrons, in which case the circular polarization would be zero. Highly sensitive observations of circular polarization could confirm or rule out an e^+e^- jet.

2.3. JET FORMATION AND COLLIMATION

Some progress — much reported at the meeting — has been made in understanding the formation and collimation of jets. These usually involve magnetohydrodynamic (MHD) calculations with varying idealizations. In general, the more closely the jet is linked to the accretion disk, the more ideal the calculations need to be in order to make the problem tractable. Currently, the calculations use the self-similarity approximation, and in the relativistic case the magnetic field is force-free. The early results suggest that thin accretion disks might not be able to drive powerful jets. Another result is that radiating shocks are unlikely to form inside the fast magnetosonic radius, at $\sim 10^{15}$ – 10^{16} cm from the central engine for a high luminosity jet.

Progress in this area will require first full two-dimensional, and eventually 3-D, MHD simulations. Resistivity should be allowed so that particles can cross field lines. What need to be studied are the relationships between the jet cross-sectional radius, the jet power, and the magnetic field on the structure of the jet. In addition, it is important to study the effects of radiative losses on the dynamics. For electron-proton jets, this will require some knowledge of the relevant plasma physics to determine the extent to which the protons share their energy with the electrons.

2.4. SIMULATIONS OF PARSEC- AND KILOPARSEC-SCALE JETS

At long last, there are now several groups carrying out time-dependent relativistic hydrodynamical simulations of jets in blazars. Despite some idealizations, these are already producing results that compare favorably with the observations, as reported elsewhere in these proceedings. The full range of parameter space needs to be explored in order to study the effects of different forms of the external pressure gradient, the reaction of the jet to different types of temporary perturbations, and the dependence of jet appearance on the values of the important physical parameters.

At kiloparsec scales, it appears that complete understanding of the details seen on VLA images will require three-dimensional, relativistic MHD simulations at high spatial resolution. This is a rather ambitious goal, but seems now to be in reach.

2.5. HIGH-ENERGY EMISSION MODELS

There is a lot of current activity among theorists trying to explain the gamma-ray emission from blazars. In general, steady state calculations are done very well, but computational difficulties have impeded progress in the crucial time-dependent case that is so important for comparison with ob-

servations. Realistic time-dependent models need to include all the various radiative processes and sources of seed photons for Compton scattering, the dynamics of jets and shocks inside them, and the evolution of the energy distribution of relativistic electrons. A number of groups have begun studies along these lines.

2.6. JET MODELS: CONCLUSIONS

It was striking to me that the theorists at the meeting had such a clear, critical view of the current state of the field, as well as an equally clear vision on what improvements to the models are likely to produce more realistic versions. Nevertheless, observers should always understand that the theorists world is, by necessity, an ideal one: the number of free parameters must be limited in order for success in application to the observations to be considered credible. The models can therefore never be expected to explain “that little wiggle” in the light curve or “that strange-looking elongated feature” in the radio image. What the theorist hopes for is an understanding of the basic physical processes that operate in an ideal jet, and that the term “ideal” becomes less disconnected from reality as the model is developed. Any observer who wants a closer agreement with reality should heed the following advice: *Smooth your data!*

In this vein, I wrote a limerick, the verses of which I sang (croaked?) at the meeting. It is best heard (or, in this case, read) with one’s favorite bottle of spirits. I have added a chorus in Spanish, sung to a well-known Spanish drinking song that should be obvious.

The Theorist’s Lament

There was a young theorist from Spain
Whose success with HD models was plain
But other theorists agreed
It wasn’t MHD
So they ignored all the data it explained!

Chorus:
Ay, ay, ay, ay
La vida de un teórico es desesperante
Crea modelos despanpanantes
Que luego son destruidos
Por datos extravagantes!

There was this shock model of mine
 That seemed to fit light curves just fine
 But certain observers said
 “The shock model is dead
 ’cause it can’t fit this flux from ’89”

[Chorus]

The moral of this sad story is: Be kind to your neighborhood theorist, who knows full well how idealized his/her models are and how poorly they often fit the data. Besides, without the theorists, where would you get the models you can destroy in the interpretation sections of your observational papers?!?

3. Multi-Frequency Support for High-Energy Observations

3.1. INTRODUCTION

In this section I summarize the discussion and conclusions of the workshop on multi-frequency support of high-energy observation. I shall emphasize the importance of long-term monitoring programs, both in the optical and at radio wavelengths. These are needed not only for statistical studies but also to get knowledge on the history of individual sources, the frequency and amplitude of outbursts and so forth. They are the only appropriate tool to evaluate possible correlations of outbursts at different frequencies. Clearly, the efforts for long-term monitoring in the optical need to be strengthened. In contrast, the event-monitoring is regarded as functioning in principle, but the systems for sharing information need improvements.

In some sense now is not the ideal time to consider improvements for the multi-frequency support of high-energy observations. Apart from the OJ-94 project, which was triggered by a theoretical prediction, the detection of more than 50 AGN by EGRET has been the driving force for many of the multi-frequency observing campaigns. The surprising finding that a subset of AGN, which subsequently has been recognized to be those objects which are blazars, emit the bulk of their bolometric luminosity at γ -ray energies, and that a large fraction of these objects are variable even on the smallest observable time scales, has led to the insight that observations in only one frequency regime are insufficient. The standard γ -ray transparency arguments imply that the emission is Doppler-boosted and thus originates in a jet, similar to the radio synchrotron emission and part of the optical and X-ray flux. Simultaneously observed spectra from the radio regime to

TeV γ -rays are therefore the appropriate tool to discriminate between the models.

However, there is only a little time left to make such observations. For the next few years the observational coverage at X-rays and above 100 GeV will be very good, but in the range of 1 MeV to 50 GeV there is no instrument scheduled to be flown past the death of EGRET aboard the Compton Gamma-ray Observatory. EGRET is running out of gas, and besides that is also suffering a slow deterioration in the performance of the spark chamber. A possible successor named GLAST did well in NASA project studies, but is still far from funding. So in the foreseeable future there will be no instrument which allows us to continue the multi-frequency spectral monitoring of AGN. We can expect the Čerenkov technique to work at lower energies, possibly down to 30 GeV. These telescopes are more sensitive to small fluxes than EGRET, but can only observe one source at a time. Furthermore, absorption by the intergalactic infrared background and possibly intrinsic cut-offs will prevent a large fraction of AGN from being observable at or above 100 GeV. Prime targets will be rather nearby BL Lacertae objects as well as galactic transients and superluminal sources. The main focus here will be studying rapid variability. A similar trend is obvious at hard X-rays where most forthcoming instrument are best suited to, or even dedicated to, timing and rapid variability observations.

In a few years the field of high-energy observations will experience a change in direction from spectral monitoring to rapid variability studies. This implies that the requirements for multi-frequency support will change accordingly. In these notes I will briefly review what we have learned technically from recent multi-frequency campaigns and I will discuss ways to improve the support of the remaining EGRET observations of blazars.

3.2. REQUIREMENTS FOR MULTI-FREQUENCY MONITORING

This discussion is split into two parts, the first is devoted to long-term monitoring and the latter deals with coordinating observations in response to an unusual event of any kind.

3.2.1. *Long-term monitoring*

Long-term monitoring data on individual sources are extremely important for determining the degree of correlation between high-energy outbursts and emission at other wavelengths. Not only is knowledge of the flux level at outburst and in quiescence necessary, but also a determination of the frequency of outbursts and the source variability time scales. It is my personal view that in some of the early claims of correlated variability between γ -rays and the optical or radio emission we have been too uncritical. We

neglected the distinction between correlated activity in the general sense, which we often find, and correlations of rapid events. Some AGN have high optical fluxes when they are also bright at γ -rays. But does that allow us to relate the one-day γ -ray flare to the one-day optical flare we observed a few days later? This is an issue beyond the inaccuracy of the term correlation. It is rather an illustration of the fact that a careful consideration of the multi-frequency history of a source is required, which can only be done on the basis of long-term monitoring data. Finally there is no question that such data are also valuable for statistical studies.

Everyone who has experience with program committees knows that the best and only way to perform monitoring of many sources over a long time is to have no such committee involved. Dedicated instruments seem to be available in the radio regime with the Metsähovi station and the telescope of the University of Michigan. The situation in the optical is less advantageous. This leads to situations like that of the OJ-94 project where a major fraction of the optical data was provided by Paul Boltwood, i.e. by an amateur who observes with a 7-inch telescope and a self-made CCD in the backyard of his house in Ottawa. As a result optical long-term coverage for most sources is insufficient. One way to go may be small robotic telescopes which need limited manpower to operate. Another way could be to get Colleges and more amateurs involved. A problem with the latter strategy surely will be the required effort for the selection of sufficiently serious and careful amateurs. Also, scientists have expressed their interest in optical polarization data. It is doubtful whether such difficult measurements can be reliably done by amateurs.

The most important issue for the moment however is a harmonization of target lists. It seems to me that currently each observatory has its own list of monitoring sources with little or no overlap between the lists at different frequency regimes. As far as support for high-energy observations is concerned this is not a satisfying situation. We strongly recommend that all groups who do monitoring campaigns, especially in the optical, include a set of ‘common’ sources in their target list, e.g. the AGN detected by EGRET or the compact sources observed by Čerenkov telescopes. This still allows each group to do their research programs on well-defined samples, but on the other hand makes sure that for a group of interesting sources good long-term light curves in the optical and in the radio range are produced.

3.2.2. *Event monitoring*

With the advent of EGRET and its detection of many AGN as strong and variable emitters of high-energy γ -rays, observers throughout the world have become interested in organized multi-frequency campaigns that parallel high-energy observations. Unfortunately, the sources have often been

“on vacation” during the observations, showing little or no activity, so that Target-of-Opportunity observations have become more en vogue. In this mode unusual activity at high energies trigger closely sampled observations in the optical and radio range or vice versa. Correlated observations at X-rays and γ -rays still have to be organized in advance and are undertaken somewhat reluctantly by the observatory program and time allocation committees, with the exception of a few highly promising sources.

The event monitoring has brought some interesting results though in many cases the studies suffer from missing long-term light curves. Since in the most extreme case an outburst has been observed on a time scale of half an hour, one will want to obtain a very close sampling in the multi-frequency follow-up observations with about sub-day time scale in the optical and day time scale at radio frequencies. This implies that many observatories, especially in the optical, have to be involved.

Communication clearly is the key in this business, and that in two senses. The first sense is that a functioning alert system is required, which spreads the information on an unusual event to observatories throughout the world, similar to the Bacodine system for bursts. In the OJ-94 project such a system has proved its capabilities with observers who had agreed before to serve on this campaign. In the general case the effect of surprise will be much larger. What we need in future is a system which can be triggered by a number of experiments from X-rays to TeV γ -rays, and which is faster than the IAU telegram system, since we will not want to wait for two days before we start multi-frequency observations for a one-hour TeV flare. This will be especially true when EGRET is no more and we observe nearby BL Lacs and Galactic sources at hard X-rays and TeV γ -rays.

The second sense in which communication is important concerns the availability of observing schedules for high-energy observatories. A large fraction of the observatories make their schedules publicly available somewhere on the Web, but there is no mother page which provides links to all the observatory pages. As a result the system is somewhat unorganized. Public schedules could also give some advance warning that an outburst may be observed, and thus help observers in monitoring the event. The problem with such a mother page definitely is that someone has to maintain it. Each one of us felt the necessity of an organizer on the Web, but no one volunteered to do the work.

3.3. CONCLUSIONS

In this section I have discussed a few problems and their possible solution for the multi-frequency support of high-energy observations. We have seen that information is the *conditio sine qua non* in this business. Everyone in

our discussion panel expressed their commitment to improving the communications networks and fast response capabilities of the community as well as continuing and expanding long-term monitoring programs. The two main multi-frequency campaigns in the remainder of the EGRET era (10 weeks on 3C279 and 4 weeks on 0528+134) will be a test of how efficient we can get in the near future.

With the already discussed change of direction in high-energy observations fast approaching, the requirements for the multi-frequency support can only get more demanding. Short time scale phenomena need closely sampled light curves to be studied. On the other hand, for Galactic sources long-term monitoring will become less important, partly since the sources are often absent between outbursts and partly since outbursts are generally temporally well separated. This is advantageous in the light of the low typical radio fluxes in the milli-Jansky range which require synthesis telescopes and hence committees. The interests of the long-term monitoring people and the interests of the event-monitoring people will diverge slightly, but that doesn't imply that the requirements for the monitoring get less difficult. Galactic sources tend to be active for several weeks with a lot of substructure in the light curves. The most prominent example is surely the 470 keV feature of Nova Muscae 1991, which was observed to last for only about ten hours. Here event monitoring will need sampling on sub-day time scales sustained over several weeks. This requires a high availability of telescopes, especially at optical wavelengths. This together with the short advance warning time for outbursts will probably favor robotic telescopes once they can be produced in series at a sufficiently high level of mechanical and electronical stability.

Finally let me spend a few lines on the interaction with the rest of scientific community, with special emphasis on theorists. What we have done so far is mainly provide simultaneously observed multi-frequency spectra of objects at a given time, which then can be compared to what the models predict. To no one's surprise, all models have been able to fit these spectra, irrespective of whether the source was in the state of an outburst or in quiescence. The drawback here is that we have often an equal number of model parameters and true degrees of freedom in the data. We have seldom seen model fits which used the same basic parameters such as Lorentz factor, inclination angle, accretion disk luminosity, and so forth to reproduce the multi-frequency spectra of a source at various states. What we require in the future is multi-frequency spectra at different stages of an outburst as well as the theory predictions for these. I would like to see how an instantaneous release of energetic particles would find its way through the electromagnetic spectrum in the Inverse-Compton models and the Proton-induced-cascades and compare that to what we see during outbursts. Theorists have just

started to work on such calculations, and I am sure that in a few years this kind of research will prove to be highly valuable for the understanding of the blazar phenomenon.

4. Monitoring of Blazars

4.1. LONG-TERM SYNOPTIC MONITORING

The “monitoring” group discussed the question of whether long-term optical monitoring might be approaching the point of diminishing returns. The Florida team, for example, now has 27 years of internally consistent data on as many as 200 sources. What will we learn from extending observations of this kind? While there was no general consensus, I pointed out that a number of the Florida objects display long-term, possibly cyclic, changes in their base levels that are not defined even by a quarter-century of data. It was further observed that monitoring of this kind frequently detects outbursts that then become the subject of intensive and highly profitable campaigns by the entire AGN community.

Several participants argued for the establishment of a dedicated global network of moderate-size telescopes for the purpose of providing 24-hour coverage of a limited number of objects, especially during outburst phases. There was discussion of whether such instruments should be manned or robotic, although the cost and complexity of the latter was recognized. There was a general feeling that the interested members of the community should undertake to organize and lobby for funding for the establishment of such a network. I suggested that such a network already exists in the form of numerous underutilized working telescopes, with willing observers who need only to be organized, encouraged, and provided with very nominal funding. A question was raised as to whether those engaged in monitoring should agree on a single frequency band unless they undertake multi-frequency observations. While this did not provoke extended discussion, one point of view was that the V band would be preferable for historical reasons, such as tying in with earlier photographic observations; however, it was pointed out that, given the characteristics of the now universally-employed CCD detectors, the R band is easier to use because of the much shorter exposures it allows. Meg Urry has argued for the establishment of a dedicated space telescope for 24-hour optical observations of AGN; there was a rather general feeling that the costs of constructing, launching, and maintaining such an observatory would dwarf the cost of the proposed ground-based network.

It was pointed out that with the demise of the International Ultraviolet Explorer spacecraft, and the incipient demise of the EUVE spacecraft, the AGN community is losing far-ultraviolet coverage of its sources. However, a

counter-argument was put forward that, since it has been shown that there is a close correlation between the far-uv and visible-band observations, the UV lacuna can be filled by better ground-based observations.

Several times during the Workshop the question was raised as to whether one might rely on amateur astronomers to augment the professional ranks in providing AGN data for either long-term observations, or during short-term campaigns. A shining example is the beautiful observations provided by the Canadian amateur Paul Boltwood, who presented his work during the conference and was present at this workshop. Paul noted that he had spent tens of thousands of dollars and thousands of hours constructing, automating, and operating the Boltwood Observatory. It was his educated opinion that extremely few amateurs would be in a position, either time-wise or dollar-wise, to duplicate his effort. He is, further, a professional computer expert, which played a major role in automating the Boltwood Observatory. Paul, however, very kindly volunteered to advise any other advanced amateurs who might wish to follow in his footsteps.

4.2. MULTI-FREQUENCY CAMPAIGNS

As in the case of long-term monitoring, the question was raised as to whether we are reaching the point of diminishing returns with intensive multi-frequency campaigns centered on outbursts of active sources. Dick Miller expressed the opinion that we are indeed reaching such a point of saturation unless - and this was an important qualification - new techniques are brought to bear during the campaigns. There was general agreement that multi-frequency campaigns would be of much greater value if intensive monitoring were carried on for several months surrounding an outburst. This would aid in placing the flare in context in the midst of more normal behavior. It was of course recognized that initiating a campaign in advance of an outburst would, in our present state of understanding, require the use of a crystal ball!

4.3. MICROVARIABILITY

It was recognized that the present popularity of microvariability studies is at least in part an artifact of the realities of telescope scheduling. It is much more feasible to obtain a few consecutive nights during which microvariability runs of a few hours each can be conducted, than to obtain the many nights scattered over a long period of time that are required for long-term studies. Dick Miller pointed out that thus far there have been no real microvariability "campaigns." He urged the desirability of such campaigns that would provide 24-hour continuous coverage, without gaps, for periods of at least a few days. Needless to say, this would require the participation

of observatories appropriately spaced in longitude, with sufficient redundancy to mitigate the effects of local weather. Based on his own extensive experience in the field, Dick suggested that definitive and unambiguous microvariability results require observers to aim for errors in the range of 0.01 to 0.02 magnitude, with an upper limit of 0.04 magnitude. The exposures required to achieve such precision then of course place constraints on the time resolution that can be expected during a run.

4.4. DATABASE

The group discussed at length the desirability of establishing a common database for pooling information on AGN variability. There was general agreement that this would be a valuable resource, but it was also recognized that there are a number of problems with implementing it. A central problem, of course, is that of protecting the rights of the original observer until he/she has obtained adequate credit; this is especially crucial where the work is funded by an agency that expects to receive due recognition for its investment. If such problems can be solved, an attractive possibility is to collect the observations in a site on the World-Wide Web, which can be accessed immediately by all users. An additional difficulty is the question of format in presenting the data. An extended discussion concluded that if the burden of converting to a common format were placed on the observers, this added work would have the undesirable effect of discouraging participation. The final recommendation was that observers should contribute their data in their own formats, with any necessary conversions being left up to those who wish to use it. A suggestion was made that instead of tabulating the observations, the web site should merely list the names and addresses of observers in a position to supply the observational results; this alternative proposal did not receive strong support.

5. Host Galaxies and Environments

5.1. INTRODUCTION

While the other workshops were focusing on direct manifestations of blazar activity (jets and the emission at all wavelengths that comes from the jet and whatever is the “central engine” of blazars), a small group of us were charged to discuss the “houses”, “neighborhoods”, and “hometowns” of blazars. The motivations for studying the environments of blazars (which in theory we took to include BL Lac objects, OVV’s, and variable high polarization quasars, but in practice we tended to focus on BL Lacs) are to identify the parent populations of a phenomenon that is believed to be strongly aspect-dependent, to understand whether or not certain envi-

ronments are necessary for the “birth and maintenance” of a blazar, and to investigate any effect the blazar has on its home (e.g. triggering star formation, etc.). Perhaps just a reflection that the previous three days of talks and posters had already covered our current understanding of blazar environments, our workshop discussions only briefly touched on the current state of knowledge (summarized in the next subsection) and instead dwelled on what questions we would like to address with future observational programs. Here we were not shy, concluding that we would like to know more about the environments in all dimensions – physical (1 kpc to 1 Mpc) and temporal (from the current epoch to high redshift). Some of the many questions we considered and examples of the possible observational programs that might provide the information we desired are discussed in the third subsection of this summary.

5.2. WHAT WE THINK WE KNOW

There has been a great deal of progress made in just the past few years in efforts to image the host galaxies and cluster environments of BL Lac objects from the ground (see various contributions to these proceedings, as well as Falomo 1996, Wurtz et al. 1996 and included references). The *Hubble Space Telescope* is also beginning to contribute to the study of the host galaxies (see contributions to these proceedings by Treves and Jannuzi and Falomo et al. 1997 for examples). While the sample of objects that have been well observed remains small (well under 100), the data are generally consistent with the host galaxies of BL Lacs being elliptical or bulge dominated galaxies that are similar, perhaps identical, to those of FR I radio galaxies. There is still debate over whether all BL Lacs are in ellipticals and whether the distribution of host galaxy properties is more similar to the host galaxies of FR I or FR II radio sources. However, convincing spiral hosts have proved extremely rare (only two current examples, see for discussion Wurtz et al. 1996) and the proper classification of these two objects is still being debated. The imaging programs are also yielding information on the incidence of close companions, allowing the first investigations of the role of interactions and mergers in triggering and feeding blazar activity, but this work is just beginning.

Progress is also being made in studying the larger scale environments through wide-field imaging of BL Lacs and control fields. Again, the samples being studied, while small, are increasing in size and appear to confirm that BL Lacs avoid rich clusters, but might still be drawn from a subset of FR I radio sources (see e.g., Wurtz et al. 1996).

5.3. WHAT MORE DO WE WANT TO KNOW?

While the progress made in imaging studies of the hosts and environments of BL Lacs has been significant, there are possible problems with what has been done and a great deal more that needs to be done. This is perhaps best demonstrated by listing some of the many questions that came up during our discussions:

Given the experience from comparing HST and ground-based observations of quasar host galaxies, how robust are the existing results and are additional checks warranted? For discussion of the comparison of ground-based and HST results see for example the work of Bahcall et al. (1997) and references therein, and McLeod and Rieke (1995) on the host galaxies of AGNs. In particular the discussions on the problems of extracting useful measurements on the hosts – problems that only increase when the angular scales of the objects are smaller, as is the case for more distant objects – when the nucleus is very luminous.

Even with excellent imaging results, how do we know that all of the surrounding nebulosity we see around blazars is star light? Is any of radiation scattered light or emission lines from gas? If the surrounding nebulosity is produced by stars, are they old, young, or a mix of populations? Are the companion objects seen in some images really close companions or substructure in the host galaxy? If galaxy–galaxy interactions are really critical in triggering a blazar, how strong an interaction is needed and what implications does this have for the birth rate as a function of cosmic time and the lifetime of individual objects?

Do all blazars have broad line regions (BLRs)? If they do, what is the range of the properties of the blazar BLRs and how do these properties compare with those of the possible parent populations? If they do not, why not? Is there a very hot gas component in/around blazars? Are blazars at the center of cooling flows? How does fuel get to the central engine?

Are all blazars members of a single class (requiring that BL Lacs, OVV's and variable highly polarized quasars all come from the same parent population, which seemed unlikely to those of us at the workshop) or do the environments of these different subclasses provide clues to why the objects appear to have some significant differences (e.g. see work of Gabuzda and collaborators for some possible differences), despite sharing the dramatic blazar characteristics?

Do the properties of blazars at high redshifts ($z > 0.6$) differ from those of low-redshift samples? Do significant numbers of high-redshift blazars even exist? Can BL Lacs and blazars be related to other AGNs in an evolutionary- or luminosity-based sequence?

5.4. HOW DO WE GET THE ANSWERS?

The end of the 1990's and the next century will see continued growth in the observational capabilities available to the astronomical community and enable many of the questions listed above to be answered. In summarizing the ideas from our workshop for the entire conference, we decided to provide examples of how new observations and observing capabilities could be brought to bear on some of the unanswered questions, rather than trying to provide guides to answering all of the questions we had listed. We tried to highlight in each case how the proposed observations could lead to the determination of physical properties of the blazars or their environment. We have reproduced three of the examples below.

5.4.1. *Spectroscopy With Large Telescopes*

Extensive spectroscopic follow-up of the light from blazar host galaxies, close companions, and host cluster members will provide answers to many of the unanswered questions. Lots of photons (i.e., big telescopes) and high spatial resolution (excellent site, telescope, and instruments) are necessary for success. When all of these things are available, as is clearly demonstrated by the contribution from Joe Miller to this conference with his observations from the Keck I telescope, one can easily obtain excellent spatially resolved spectra of the *star light and H II regions* in the host galaxies of quasars. It should only require the increased availability of large-telescope observing time (which should be more widely available once the VLT, Gemini, and other telescopes are in operation), a few proposals, kind comments from time allocation committees, and some good weather before large numbers of blazar host galaxies can be observed in a similar manner. Studies of the stellar populations of the host galaxies and investigations of the role of interactions in blazar activity should therefore make rapid progress in the near future.

5.4.2. *Observations at Non-Optical Wavelengths*

The masses of the host clusters as well as the presence of hot gas and “warm absorbers” in BL Lacs can be studied with X-ray telescopes, and we expect continued progress in these investigations using both existing and future (e.g., AXAF) X-ray observatories. Information on smaller spatial scales should continue to become available from observations at millimeter through radio wavelengths, including studies of Faraday rotation as a diagnostic for hot plasma surrounding the central source. Millimeter, sub-millimeter, and IR observations will provide information on the dust and gas content of the host galaxies. Maps of the gas and dust content of the hosts, when combined with high spatial resolution imaging and spectroscopy of the stellar light (which will eventually be aided through the

use of coronagraphs and/or HST) might allow detailed investigation of the structure of the host galaxies and studies of the available fuel reservoirs of the blazars.

5.4.3. *Extensive New Surveys*

In addition to discussing how to answer the questions listed in the previous section, we also discussed how our current knowledge of the environments of BL Lacs might be biased and how this might be corrected with additional work. First, most of our knowledge of the host galaxies and cluster environments of BL Lacs comes from studies of low redshift (< 0.6) objects and those BL Lacs which do not have large ratios of observed nuclear brightness to surrounding nebulosity. This is not surprising, and may simply be a consequence of studying biased samples. Existing samples are flux limited, and are therefore biased against finding all but the most luminous distant objects. Even the best existing blazar host galaxy studies have relied on samples whose primary selection criteria depended on blazar properties (selection at wavelengths where the radiation is dominated by the non-thermal beamed emission), and are therefore further biased towards the extreme members of the population. Finally, our ability to detect the surrounding nebulosity requires very high spatial resolution and extremely good dynamic range. A partial solution, although expensive in terms of effort and telescope time, is to construct even larger samples of blazars by extending follow-up of x-ray and radio surveys to even lower flux levels. This would allow the construction of large samples with a larger dynamic range in the source properties. An obvious candidate for follow-up is the FIRST radio survey, currently being carried out using the VLA, but there are certainly other suitable surveys in progress or planned.

5.5. EXCITING TIMES

In general the workshop participants were excited about the prospects for significant progress in the future. The most significant challenge to progress that we identified was not scientific, but rather the need to effectively communicate to the telescope time allocation committees and the research funding agencies the nature and degree of progress that is being made in the study of blazars so that this work will be enabled in the future. This later discussion, as was appropriate, took place over some good wine and beer, rather than during the main session of the workshop.

6. A Very Well Deserved Thank You!

All of the workshop chairs would like to thank, on behalf of all the conference participants, the wonderful organizers of the conference. The meeting

was informative, productive, and enjoyable only because of the extensive preparation and extremely hard work of both the scientific and local organizers. Special thanks have to be given to Jose Antonio de Diego, Sumpsi Montagut, and the main driver for the entire meeting, Mark Kidger. Thank you!

References

- Bahcall, J. N. et al. 1997, Ap.J., 479, in press
Falomo, R. 1996, M.N.R.A.S., 283, 241
Falomo, R., Urry, C. M., Pesce, J. E., Scarpa, R., Giavalisco, M., & Treves, A. 1997, Ap.J., 476, 113
McLeod, K. K., & Rieke, G. H. 1995, Ap.J., 454, 77L
Wurtz, R., Stocke, J. T., & Yee, H. K. C. 1996, Ap.J.S., 103, 109